Student Design of a Bipropellant Liquid Rocket Engine and Associated Infrastructure

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Overview

- Sun Devil Rocketry – A Brief History
- Why Liquid Propulsion
- Liquid Rocket Engine
  - Nozzle and Combustion Chamber
  - Thrust Chamber Cooling
  - Propellant Injector & Manifold
  - Ignition and Engine Start-Up
- Ground Support Equipment
  - Propellant Feed and Management
  - Data Acquisition and Control
  - Test Stand
  - Test Site
- Next Steps
- Contact Info

Sun Devil Rocketry – A Brief History

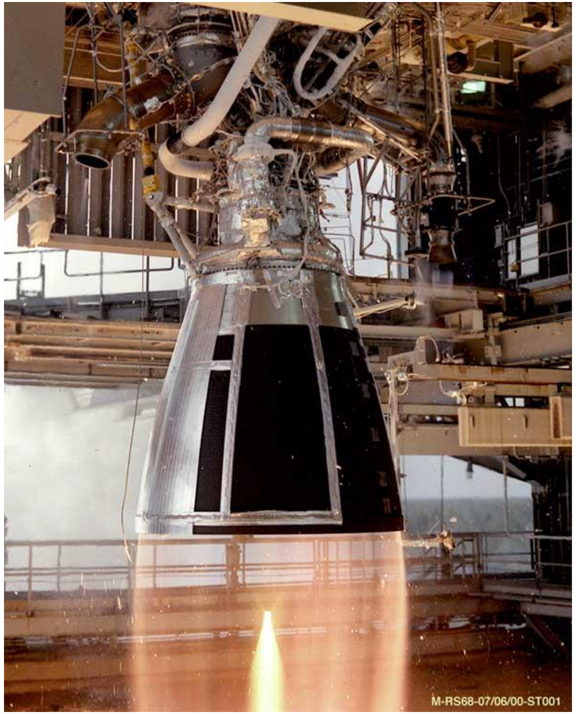
- Founded as Daedalus Astronautics circa 2003
- Student-led research and design team:
  - High-power rocketry
  - Solid, hybrid, liquid propulsion design teams
  - Introductory program
  - Independent research projects
  - K-12/Community Outreach
- Mission: *“Prepare students to become leaders in aerospace through meaningful projects, interactions, and experiences.”*

Independent research: a toroidal aerospike nozzle integrated with an N_2O/HTPB hybrid motor

K-12 outreach: a particularly adventurous rocket design

Why Liquid Propulsion?

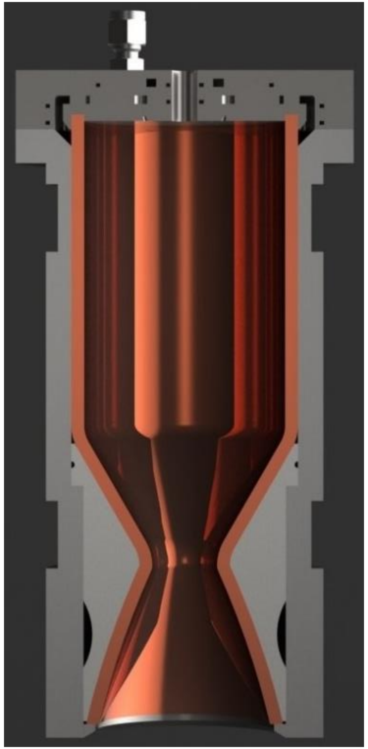
- Remember the mission, “*Prepare students to become leaders in aerospace…*”
  - Liquid rocket propulsion remains a highly relevant aspect of modern spacefaring systems
  - Project-based engineering experience
    - Routing and pressurization of reactive fluids
    - Management of thermal extremes
    - Data acquisition and control for live experimentation
    - Test planning and operations
- Interesting, exciting, challenging!



Aerojet Rocketdyne RS-68

Top Level Requirements

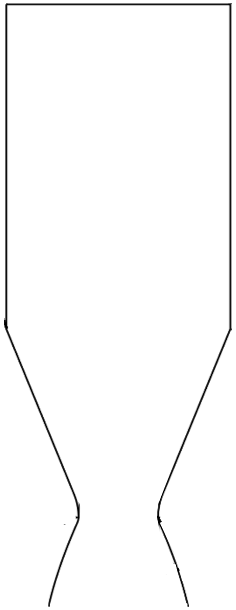
- Defined multiple requirements at beginning to ensure direction and reduce headache
  - Thrust – 405 lbf
  - Chamber pressure – 250 lbf
  - Burn time – 5 s
  - Propellants – Liquid Oxygen and Kerosene
  - Cooling method – Regenerative
- Performed trade study to determine mixture ratio
  - O/F – 1.6



Render of thrust chamber assembly

Nozzle and Combustion Chamber

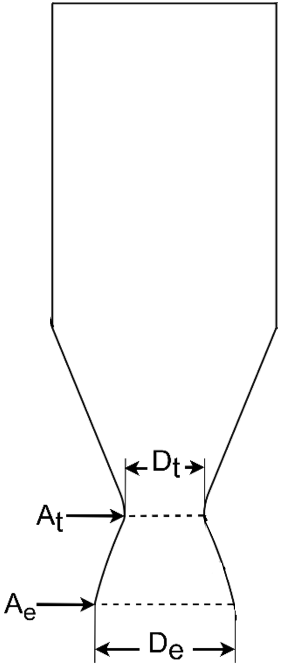
Trait	Value



Nozzle and Combustion Chamber

- Use chemical equilibrium properties from NASA CEA to determine throat, exit area

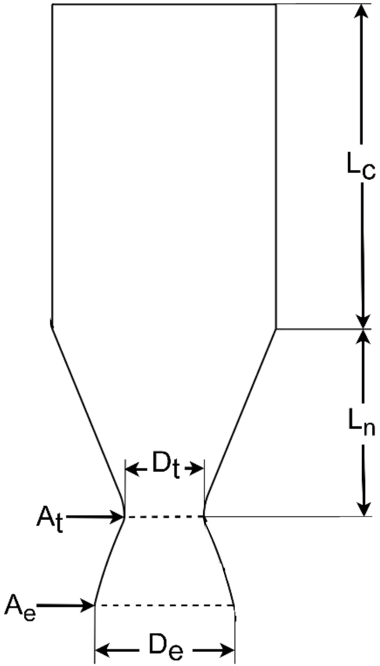
Trait	Value
D_t	1.23 in
D_e	2.15 in



Nozzle and Combustion Chamber

- Use chemical equilibrium properties from NASA CEA to determine throat, exit area
- Determine chamber length using historical correlations to throat diameter

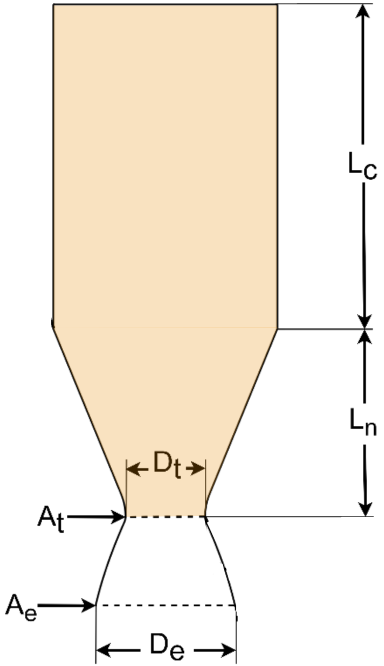
Trait	Value
D_t	1.23 in
D_e	2.15 in
L_c	4.99 in
L_n	2.89 in



Nozzle and Combustion Chamber

- Use chemical equilibrium properties from NASA CEA to determine throat, exit area
- Determine chamber length using historical correlations to throat diameter
- Assume L^* = 50 in, determine volume

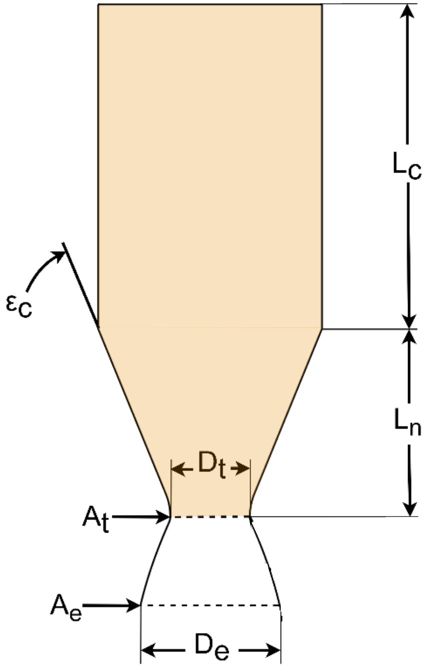
Trait	Value
D_t	1.23 in
D_e	2.15 in
L_c	4.99 in
L_n	2.89 in



Nozzle and Combustion Chamber

- Use chemical equilibrium properties from NASA CEA to determine throat, exit area
- Determine chamber length using historical correlations to throat diameter
- Assume L^* = 50 in, determine volume
- Set convergent half-angle such that Görtler instability is avoided

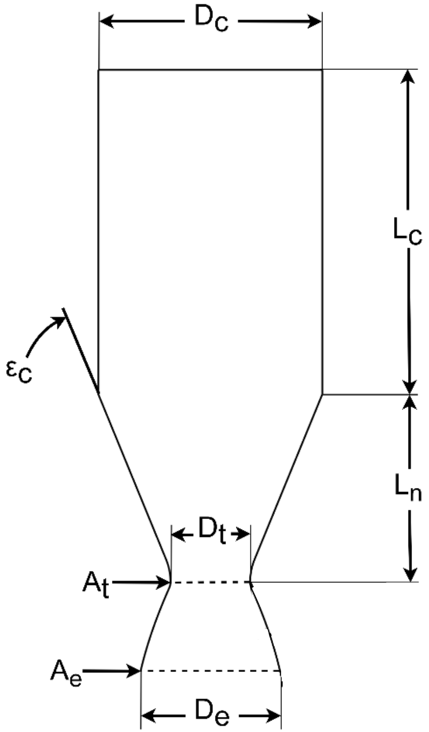
Trait	Value
D_t	1.23 in
D_e	2.15 in
L_c	4.99 in
L_n	2.89 in
ε_c	22.3°



Nozzle and Combustion Chamber

- Use chemical equilibrium properties from NASA CEA to determine throat, exit area
- Determine chamber length using historical correlations to throat diameter
- Assume L^* = 50 in, determine volume
- Set convergent half-angle such that Görtler instability is avoided
- Find chamber diameter using geometric relations

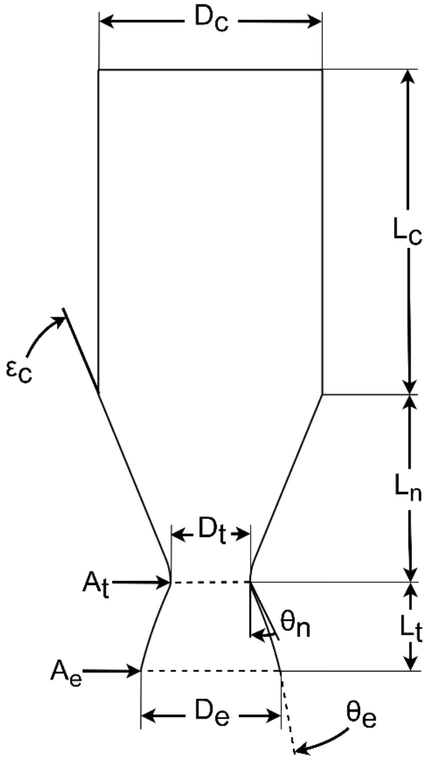
Trait	Value
D_t	1.23 in
D_e	2.15 in
L_c	4.99 in
L_n	2.89 in
ε_c	22.3°
D_c	3.45 in



Nozzle and Combustion Chamber

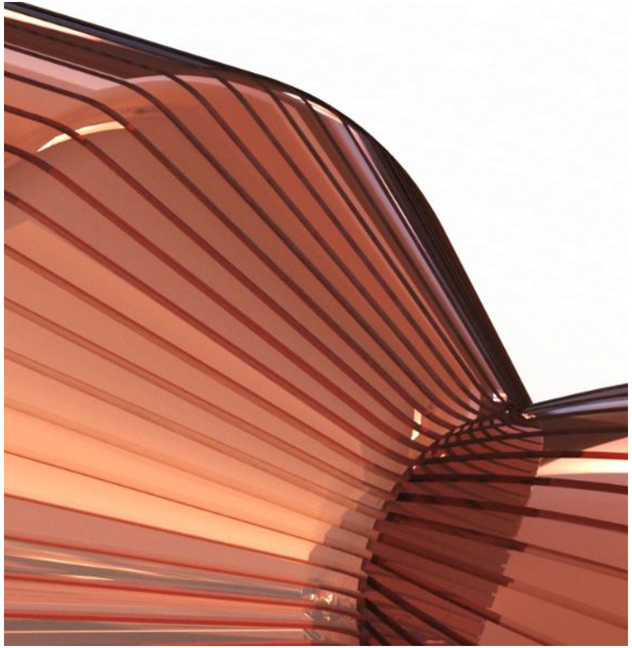
- Use chemical equilibrium properties from NASA CEA to determine throat, exit area
- Determine chamber length using historical correlations to throat diameter
- Assume L^* = 50 in, determine volume
- Set convergent half-angle such that Görtler instability is avoided
- Find chamber diameter using geometric relations
- Design thrust optimized parabolic nozzle

Trait	Value
D_t	1.23 in
D_e	2.15 in
L_c	4.99 in
L_n	2.89 in
ε_c	22.3°
D_c	3.45 in
θ_n	24°
θ_e	13°
L_t	1.37 in



Thrust Chamber Cooling

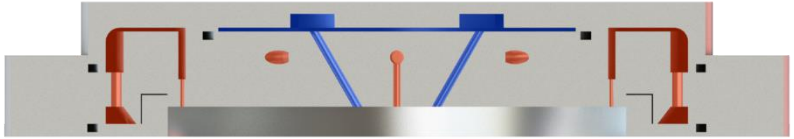
- Given high combustion temperature of ~4,400 °F, regenerative + film cooling used
- Kerosene selected as coolant, C11000 copper used as chamber liner
  - Maximum service temperature set at 840 °F
- Defined cooling system using empirical relations and Rocket Propulsion Analysis
  - (45) 1/16” x 1/16” regenerative channels which deliver propellant to injector manifold, 1.26 lbm/s
  - (30) film cooling orifices, 0.60 lbm/s
  - Predicted maximum wall temperature of 627 °F



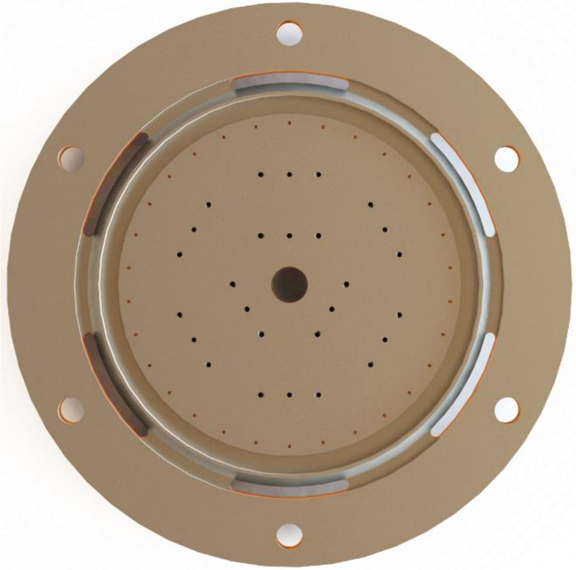
Render of copper chamber liner showing detail of regenerative cooling channels

Propellant Injector and Manifold

- Unlike triplet (O-F-O) selected as element
- Empirical correlations and given mass flow rates used to determine element geometry
  - Diameter ratio – 1.0625
  - Impingement angle – 60°
  - Impingement distance – 0.375 in
  - Element count - 9
- Total element pattern set such that mass-flux distribution is balanced and uniform
- 2-plate manifold feeds primary and film cooling elements



Cross-section of injector/manifold assembly. Blue – LOX, Red - Kerosene



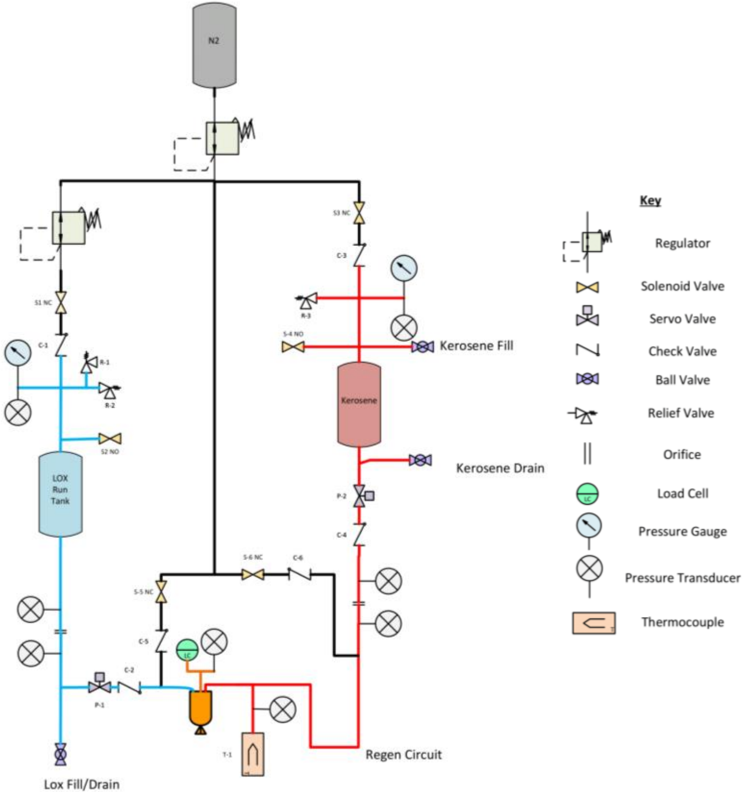
Render of propellant injector

Ignition and Engine Start-Up

- Nozzle-inserted pryogen charge selected as igniter
- AP-HTPB composite propellant used as ignition source
  - Produced by Sun Devil Rocketry's solid propulsion team
  - No metal additive is used to avoid damaging the copper chamber
  - 5 second burn time
- PROPEP used to characterize burn temperature
  - 8/3.4 AP/HTPB mixture ratio selected to generate ~1960 °F
- Initiated via nichrome wire
- Blown out of chamber following ignition

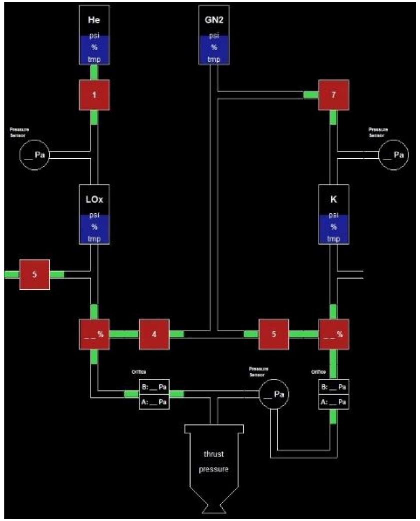
Propellant Feed and Management

- Fuel and oxidizer tanks are pressurized to 310 psig and 300 psig respectively using GN_2
- Propellant feed system incorporates multiple flow management and safety relief devices
  - Relief and vent valves on both propellant tanks
  - Servo-actuated main propellant valves
- Predominantly 0.5 in, compression fit line
- GN_2 bypass line allows for engine purge
- Liquid oxygen fill line doubles as oxidizer tank and oxidizer feed line pre-chill

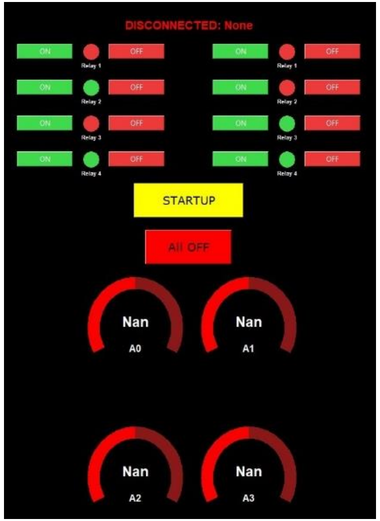


Data Acquisition and Control

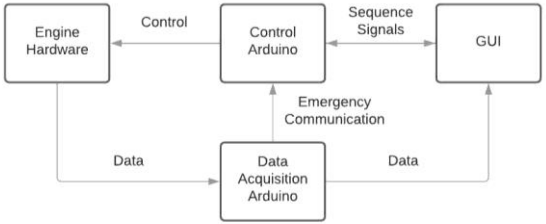
- System pressures, temperatures, flow rates, and thrust measured
  - Signals are processed based on instrumentation type
- Remote control of main propellant values and purge/vent solenoids
- Control and data acquisition are handled by separate Arduinos
- A software interface was developed to allow for live telemetry readout and system control by an operator



P&ID data display



Control dashboard GUI



Engine Hardware

Control

Control Arduino

Sequence Signals

GUI

Emergency Communication

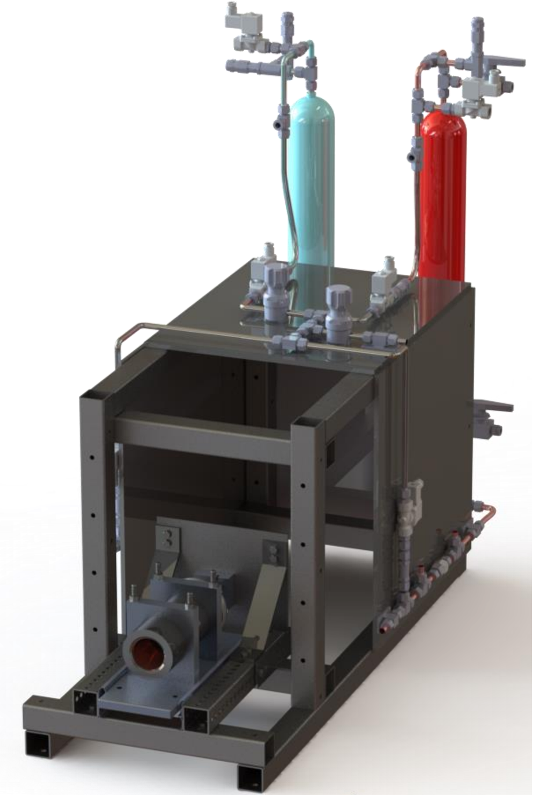
Data

Data Acquisition Arduino

Data

Test Stand

- Thrust structure comprised of square steel tubing
- Engine secured to translating sled, allowing for simplified mounting and thrust measurement
- Plumbing and data acquisition equipment reside on modular panels which may be removed for transport
- Integrated bulkhead shields propellant tanks and dewars in case of engine failure
- Test stand secured to concrete blocks using ratchet straps and sandbags



Render of test stand assembly

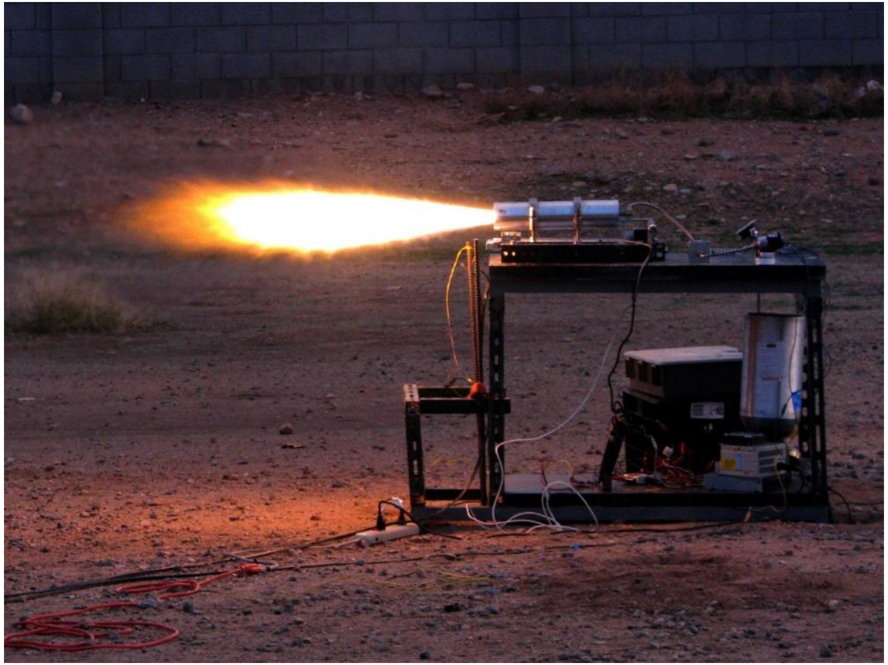
Test Site

- Local, dedicated test site
- Test article secured 140 ft from container where operations will be controlled
- Peak incident pressure distance of 49 ft is less than distance to bunker
  - Peak incident overpressure of 1 psig
  - Assumes 10% yield factor for LOX/Kerosene
- Hazard fragmentation distance of 311.5 ft requires analysis of barriers

Test site, showing personnel bunker

Next Steps

- Manufacturing, assembly, test!
  - Multiple systems must be manufactured and fit checked
  - Leak, pressurization, and flow tests
  - Operational transients must be characterized to properly sequence
  - Further development of data acquisition and control system and test site
- Learning and growth is the biggest priority



Test fire of hybrid rocket engine developed by Sun Devil Rocketry

Thank you!

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Learn more about Sun Devil Rocketry:

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